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Newsletter & Cover Design
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Contents

About the cover—Northrop Grumman ISS unveiled its design for an unmanned aircraft to demonstrate some of the technologies emanating from its new Advanced Systems Development Center (ASDC) in El Segundo, CA. Pegasus, an internally funded program, will perform a proof-of-concept demonstration with flight tests scheduled to begin later this year. Pegasus is being designed and built to demonstrate aerodynamic flying qualities suitable for aircraft carrier operations. Specific objectives include—

- Low speed aerodynamic handling qualities
- Compatibility with carrier landing systems
- Simulated landing arrestment
- Demonstrate an air vehicle management and architecture applicable to future unmanned air vehicles

Designed with stealth features and shaped like a kite, Pegasus is built largely with composite materials. The aircraft measures 27.9 feet long and has a nearly equal wingspan of 27.8 feet. First flight is planned for the fourth quarter of this year at the Naval Weapons Center, China Lake, CA. One of the first tasks of the Pegasus flight program will be to demonstrate the aerodynamic qualities of an autonomous UAV that would allow it to operate from an aircraft carrier, thus reducing the risk for carrier operations of a Naval UCAV.

Editor's Notes

The theme for this issue of *Aircraft Survivability* is Science and Technology (S&T) initiatives in aircraft survivability. Two persuasive articles by Dr. Whelan and Mr. Lockenour address how survivability is being viewed in the design and employment of unmanned air vehicles.

Another interesting article describes a successful JTCG/AS funded project in engine digital control technology that may find its way onto now- and next-generation high performance turbine engines. New control algorithms will provide a capability to detect sudden engine damage inflicted in combat or peacetime events like foreign object damage (FOD)—and then employ a damage mitigation action to minimize the damage effects and also retain realistic engine performance capacity.

Three articles focus on operations in the low altitude battlespace environment, including one by BGen James Amos, USMC, Assistant Deputy Chief of Staff for Aviation, Headquarters U.S. Marine Corps.

The JTCG/AS is supporting a Joint Test & Evaluation (JT&E) program titled, Joint Aircraft Survivability to MANPADS (JASMAN). This JT&E is now in the Joint Feasibility Study (JFS) phase and is due for review by the OSD JT&E Senior Advisory Council soon. Dr. Kristina Langer is the JASMAN technical director and has written an informative article that describes the JT&E program in general and the objectives of JASMAN.

For a change of pace, we appreciate the contribution of Dr. Richard Hallion, Air Force Historian. In his article, Dr. Hallion offers a historical review of the military experience with aircraft survivability, beginning with the end of the Vietnam war.

Being recognized as our pioneer in survivability for this issue is Mr. Mike Meyers of The Boeing Company. Mike has been active in the JTCG/AS for many years as an industry representative. After a long and distinguished career with McDonnell Aircraft Company and then Boeing, Mike will retire 30 June 2001.

As always, we solicit your comments on any of the articles or other parts of the newsletter. The E-mail address is jolleyjp@navair.navy.mil. The theme of the next issue of *Aircraft Survivability* is Credibility of Modeling and Simulation in Aircraft Survivability. We thank all of the authors in this issue for taking the time to contribute to *Aircraft Survivability.*

Finally, LTC Schwarz, JTCG/AS Central Office Director is being transferred effective 9 July 2001. His new assignment is to an OSD special program at the Pentagon. We appreciate LTC Schwarz' efforts during his tenure with the JTCG/AS and wish him well in his new assignment.

Joseph P Jolley

The Survivability Revolution at DARPA

by Dr. David A. Whelan

The Defense Advanced Research Projects Agency (DARPA) has been developing revolutionary military and national systems for over 40 years. From the Saturn V rocket to stealth technology and the Internet, DARPA programs have historically created paradigm shifts in aerospace and information. The current portfolio of DARPA programs holds the same promise—warfighting twenty years from now will little resemble current practices. Survivability is one of many areas in which DARPA programs will make a dramatic difference.

What does it mean to create a "revolution" in survivability? The development of stealth technology provides a good example. In 1977, DARPA began funding the Have Blue program, followed in 1978 by the Tacit Blue program. The Have Blue aircraft, otherwise known as the "Hopeless Diamond," made its first flight in 1981, followed in 1982 by the Tacit Blue aircraft, or "Whale." Neither of these aircraft met a complete set of requirements for a military aircraft. Yet DARPA had created two existence proofs that aircraft could fly virtually undetected by state-of-the-art radars. **That was the revolution.**

But the development of a new technology should never be undertaken without thinking about tactics. Tactics must be considered from the conceptual phases of a new capability in order to get real gains. For example, consider the synergy between electronic warfare techniques and stealth capabilities. While signature reduction might have been the principal focus early in the stealth program, it became apparent that the greatest tactical effectiveness would be achieved when electronic warfare tactics were part of the employment strategy.

In this article, I will try to describe the revolutions we at DARPA are trying to foster in both aircraft survivability and spacecraft survivability.

Spacecraft Survivability

The ability of the United States to dominate the "high ground" of space is being challenged by a rapidly increasing number of nations with space capabilities. Thus, it was very good to see that the Winter 2000 issue of Aircraft Survivability focused on space survivability. In that issue, Ball and Kolleck stated—

Spacecraft susceptibility reduction can also be achieved by providing the on-orbit satellite with some type of maneuver capability (spacecraft tactics). The ability to change orbit will allow the spacecraft to avoid getting hit by large pieces of orbital debris and meteoroids and help defeat accurate foreign tracking/orbit determination. Accurate foreign tracking/orbit determination capability is one of the biggest threats to U.S. space systems. Any effective foreign space object identification program will allow a potential enemy to possibly engage in a denial and deception program. This in turn could negate the effectiveness of U.S. reconnaissance assets and result in a mission kill without attacking any of the elements in the space system.

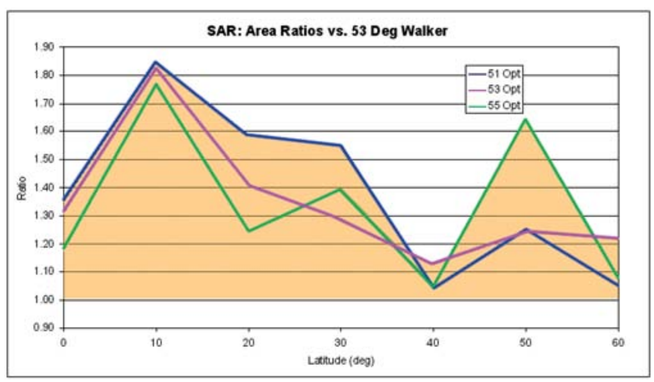

Figure 1. In addition to reducing predictability of orbits, satellite maneuverability can also be used to increase coverage. This graph shows the increase in radar coverage over a standard 24-satellite constellation when the spacecraft are maneuvered to optimize the coverage.

The fact is, most spacecraft have a maneuver capability. The reason they do not use it is that they cannot be refueled. Inability to refuel means, of course, that

maneuvers will shorten mission lifetime. Imagine if tactical jet aircraft had to be filled with all the fuel they could ever use, right when they came off the production line! Equally absurd, today, would be procuring military jet aircraft that did not have an inflight refueling capability. But spacecraft today cannot be refueled, so their fuel must be scrupulously conserved—for altitude control, for deorbiting at the end of their useful life, and for orbit adjustment in support of the occasional military crisis.

Figure 2. The small size and weight of the Miniature Air-Launched Decoy minimize its impact on the strike aircraft payload. Here three MALDs are loaded on a wing pylon.

DARPA has a program to revolutionize the way we operate spacecraft. Called Orbital Express, it will demonstrate for the first time the refueling of spacecraft on orbit. This will give spacecraft operators the ability to maneuver spacecraft to take maximum advantage of their capabilities, without fear of premature mission expiration (see Figure 1). Adversaries will no longer be able to accurately predict orbits to escape observation of hostile activities. Fuel will no longer be a treasure to be hoarded, but a commodity to be delivered when needed and used when appropriate. The survivability and effectiveness of U.S. national security spacecraft will both be enhanced by Orbital Express.

We have structured the Orbital Express program to demonstrate yet another revolutionary capability. The system will deliver and install Orbital Replacement Units (ORU) on orbiting spacecraft. This will allow capabilities to be upgraded or refurbished on orbit; long-lived, expensive hardware such as optics and structure can be kept operating rather than being discarded; and overall space system life cycle costs will come down. Rather than a human-based refurbishment scheme such as was used on the Hubble Space Telescope, the servicing missions of Orbital Express will be executed by unmanned spacecraft controlled by autonomous mission software, requiring a minimum of interaction with the ground. Orbital Express is being designed as an entire architecture rather than a specialized system, with standard interfaces and protocols, so its benefits will be available to a wide variety of spacecraft.

If Orbital Express is successful, space operations of twenty years from now will look little like they do today.

Aircraft Survivability

The advent of low observable aircraft was the first DARPA-led revolution in aircraft survivability. The F-117 Nighthawk proved its battle-worthiness in Operation Desert Storm. During some inclement nights over Kosovo, the only aircraft flying was the B-2 Spirit. These low observable aircraft deliver payloads accurately and bring their crews back.

But not all aircraft in the inventory are low observable, now or in the near future. Adversary surface-to-air missiles are proliferating and at the same time becoming more lethal. Even an F-117 fell prey to them in Kosovo. In order to help strike aircraft get to the target and back safely, DARPA has developed the Miniature Air-Launched Decoy (MALD) (See Figure 2). This 98-pound air vehicle has achieved an average unit flyaway price of only $30,000, by developing a miniature turbojet engine and using mostly commercial airframe components. The revolutionary aspect of MALD is that now there is an effective penetration aid whose cost is many times less than the threat surface-to-air missile. MALD is an example of asymmetric warfare by the good guys! With dozens of successful test flights behind it, 150 MALD vehicles will be purchased by the Air Force over the next three years in a limited production buy.

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Survivability/Reliability and the Unmanned Air Vehicle

by Mr. Jerry L. Lockenour

The fundamental consideration that has driven the use of classical survivability in the design of military air vehicles has been the high value placed on human life. For all manned platforms this "value of life" drives design features such as component reliability, system redundancy, hydraulic line and wire bundle separation, and component hardening. Unmanned vehicles, to date, have not employed the same level of survivability or reliability. They have been considered to be more expendable than manned systems. The result is that today's UAVs are very low cost. As we now consider UAVs for more sophisticated missions we must examine their survivability requirements and decide what criteria should be used to determine the appropriate numerical requirements.

There are two dominant factors that will determine the degree to which survivability and reliability are incorporated into future UAV systems. 1) The value of the payload and, in turn, the value of the overall UAV platform; and 2) mission requirement for the UAVs to operate in proximity to or cooperation with manned vehicles, either military or civilian.

The Value of the Platform. When there is no man-in-the-loop, survivability considerations can be based primarily on economic considerations, i.e., a direct trade-off can be made between replacement cost and the cost of adding survivability or reliability features. Replacement cost in the military should include the actual cost of replacing the vehicle as well as the logistics cost of resupplying it to the theater. For a fixed range/duration mission the value of the platform is a strong function of the value of the mission payload. The relationship of payload value to the cost of a hypothetical UAV relative to an equivalent manned aircraft is characterized in Figure 1. The cost of removing the man from an air vehicle (removing the cockpit and the related man support systems) is only about one-third of the total cost savings realized by the deployment of a UAV instead of a manned system. The remaining two-thirds saving comes from the design choices that are made possible throughout the rest of the vehicle. Taking an ISR mission as an example, on the lower extreme of payload, one might carry simply an optical camera. Further up the scale in payload value, a mix of RF, EO, and IR sensors may be considered. And on the very high end could be a sophisticated array of sensors similar to that found on the JSTARS or AWACS manned aircraft. As systems move up this scale, it is unlikely that vehicles would be considered "throw-away." UAVs at the "high value" extreme of the scale would likely require similar reliability and survivability as the manned equivalent.

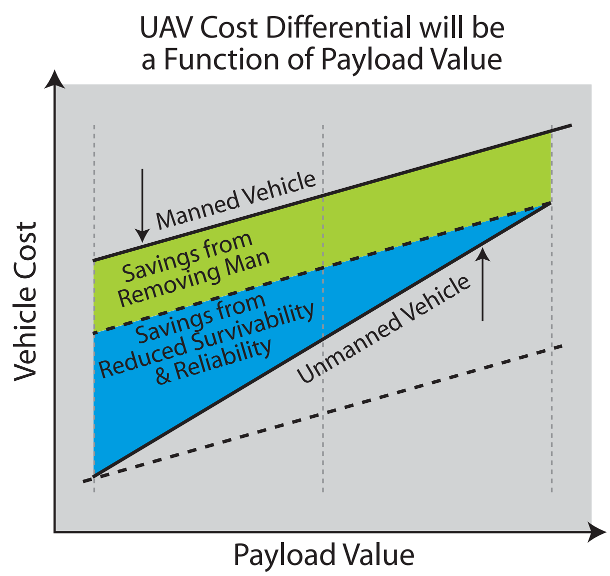

Figure 1. The relationship of payload value to the cost of a hypothetical UAV relative to an equivalent manned aircraft.

In this case, the cost savings would shrink to that of simply removing the pilot (and crew).

Operation in Civil Air Space: UAVs are facing another challenge—that of operating in civilian air corridors. Military UAVs to date have been operated in large part within the military theater and outside of civilian corridors. However, as the range of UAVs increases, and as they become more numerous, two changes must occur. One, the mission of some of them will dictate that they operate in close coordination with manned vehicles; and two, in some cases they will be required to operate in civilian airspace. The reliability requirements for such operations have not been determined. For mixed military operations, although one could choose to accept the loss of the UAV it must not endanger the manned systems. And to operate in civilian air space, there are no passengers or crew on the UAV but one must again insure that collision (in the air or on ground) with civil aircraft does not occur. The vehicle reliability must also address the possibility of a UAV coming down in a populated area.

It is projected that the consideration of survivability and reliability in the design and certification of UAVs will vary widely depending largely on the value of the mission payload and the degree to which the mission requires their operation in the presence of manned systems either in mixed military missions or in civilian air space. As mission complexity (payload cost) and operational flexibility (operating with manned aircraft) increase the classical survivability and reliability considerations will play an important role in meeting the UAV design objectives.

Jerry Lockenour is manager of Technology Development & Applications for the Air Combat Systems Business Area of the Integrated Systems Sector of Northrop Grumman Corporation. Named to his present position in March 1997, he has research and development responsibility for Flight Sciences, Weapons Integration, Vehicle Systems, Structures, Avionics, Software, Low Observables and Manufacturing Technology and Materials Development. In addition, Mr. Lockenour is responsible for the sustaining and upgrade engineering on the world wide fleet of F-5 and T-38 aircraft. Mr. Lockenour received a B.S. in Aeronautical Engineering from Purdue University in 1967 and a M.S. in Mechanical Engineering from Ohio State University. He has completed Executive Business Management programs at University of Southern California (USC) and University of California Los Angeles (UCLA). Mr. Lockenour is a registered professional engineer in Ohio and California and an Associate Fellow of the AIAA. He has taught Control Systems Design at the college level and short courses in the USA, in Europe and Taiwan. He has served on the NASA Aeronautics Advisory Committee. He may be reached at lockeje@mail.northgrum.com.

Editor's Note: In April of this year, USD(AT&L) and ASD(C3I) in the Office of the Secretary of Defense, released a consolidated unmanned aerial vehicles (UAVs) roadmap. The document presents the DoD roadmap for developing and employing UAVs over the next 25 years (2000 to 2025). The roadmap is available to download in pdf format at http://www.acq.osd.mil/acqweb/help/welcome.html.

The Low Altitude Battlespace Environment

by BGen J. F. Amos

Marine Air Ground Task Force (MAGTF) operations are constrained by the context of the international political and cultural landscape, driven by the tenets of Expeditionary Maneuver Warfare (EMW), and framed by the operational, political, and technological mandates under which the U.S. Marine Corps operates. Over the course of the next several decades, these factors will likely necessitate Marine Aviation, again, to operate in the low altitude battlespace environment.

Always a challenging environment in which to conduct operations, low altitude battlespace is particularly difficult in the realm of survivability. Yet, one of the keys to survivability in this environment is knowing what to expect. Even though the world situation is as unpredictable as it has ever been, a look at the present- and near-term environment reveals some clear trends. The trend of population explosions in underdeveloped regions will continue. By 2010, over 70 percent of the world's population will live in urban areas, and most of these within 300 miles of a coastline. Urban densities will continue to grow. Demand for resources will increase correspondingly. The migration of the world population to these littoral areas will bring together disparate ethnic, tribal, ideological, and religious values, some of which have clashed for hundreds of years. These demographic factors will drive future unrest in the littorals. The political and cultural impact caused by any civil unrest or natural disaster undoubtedly will be proportionate to the concentration and size of the population. What is also likely is that our nation will be required to respond to events in these predominantly urban littorals. The Marine Corps is prepared for this response.

Complex challenges confront the military commander. At the high end of the spectrum lies major theater warfare, the proliferation of sophisticated weapons, and weapons of mass destruction. At the low end resides a greater demand for military operations other than war, the specter of trans-national threats, and increased non-aligned international terrorism. The diversity across this full spectrum of conflict highlights the demands with which the military in general, and the Marine Corps in particular, must contend. To be capable of responding to a multitude of missions across the spectrum of conflict is a signature characteristic of the vision of the Marine Corps, and it is likely the Marine Corps' involvement in these missions will continue to rise.

There is no near-term relief in sight for the high paced military operational tempo that has come to be accepted by the American public as the norm. This increased operational tempo obviously entails increased exposure to hostile forces and agents. This increased exposure in turn mandates developing and acquiring measures to counter, negate, or avoid the threats posed by these forces and agents. This will require that our forces be able to locate and identify all hostile threats and address them in real time. These are key factors in MAGTF aviation survivability.

As Marines, we organize for combat in response to the situation and the expected environment providing the combatant commander with a scalable force (another signature characteristic of our vision). We are trained, organized, and equipped as an expeditionary force capable of being deployed and employed anywhere in the world on short notice. This approach is reflected in our core competencies: ready to fight and win, expeditionary in culture, combined arms operations, task organized, integrated reserve expertise, forcible entry from the sea, naval in character, and joint competency. As we conduct our operations, we will do so with the expertise resident in these competencies and within the construct of our capstone operational concept, Expeditionary Maneuver Warfare (EMW).

Built on the twin pillars of our philosophy of maneuver warfare and our expeditionary heritage, EMW describes the unique contribution of the Marine Corps to the nation's security. The Marine Corps will

provide America with a single, integrated force that enables Joint, Combined, and Multi-national operations. The Marine Corps will maintain sustainable forward presence and the ability to rapidly project multidimensional combat power to influence events ashore.

From a standpoint of aviation survivability, EMW primarily addresses susceptibility reduction (as opposed to vulnerability reduction, which, in the current fiscally-constrained climate, is always difficult to modify). EMW transforms the operational mindset. It espouses maneuver and naval warfare (vice attrition warfare) using the sea as maneuver space. EMW generates overwhelming tempo, using swift strikes against critical enemy vulnerabilities to create confusion wherein the enemy does not know how to react. By conducting over-the-horizon operations, it allows Marine Aviation to reduce the probability of detection. It increases the element of surprise, and at the same time affords increased protection to naval platforms with embarked MAGTF aviation assets. It significantly reduces predictability, as it leverages the advantages of sea basing, and thereby greatly reduces both the footprint ashore and the overall susceptibility to attack—all of which increases survivability.

As forward-deployed, first-to-fight forces, a few operational certainties confront the MAGTF and magnify the low altitude survivability challenge. First, the missions of the Marine Corps will, at times, require exposure to the threat with flight operations in the heart of hostile weapons engagement envelopes. Second, the Marine Corps will continue to answer our nation's call without the benefit of choosing the time or place for every conflict. Third, MAGTF aircraft will fly profiles (into urban areas, embassy compounds, etc.) that place them at the peak of susceptibility to weapons engagement. More specifically, we will continue to fly at low altitudes in high threat environments—because some missions will demand it. Our challenge is to do so—and survive.

Legacy and future aircraft possess markedly different capabilities. For example, with its significantly increased speed, range, and payload, the MV-22 Osprey will revolutionize assault support operations and will be one of the most survivable aircraft available. Likewise, the Joint Strike Fighter and the UH-1Y and AH-1Z upgrades will largely change the operational employment characteristics of our expeditionary aviation assets and also shrink susceptibility windows. In contrast, the legacy CH-46E employs much of the same configuration and retains many of the susceptibilities it did when it first saw service in Vietnam. While future aircraft will come to the battlefield well suited to address present and projected threats, existing legacy aircraft have more formidable challenges. A review shows these aircraft have not fared well in the budget planning process when survivability enhancements have been addressed. Initiatives to address basic reliability, maintainability and safety have consistently (and properly) pre-empted such upgrades. Hence, vulnerability and susceptibility have historically been an operational constant and a challenge for a large percentage of Marine Corps aircraft.

Adapting to these challenges requires Marine Aviation to continue to organize, train, equip, and sustain forces for dynamic, expeditionary operations. The key to accomplishing this is the development of new initiatives for current/legacy systems that address the challenges that lay ahead while focusing on aggressive modernization of our aviation systems. The current political and developmental curves may have intersected now to present a unique opportunity to enhance the baseline survivability of MAGTF aviation. This then becomes the challenge for industry. The mix of legacy and new aircraft in the MAGTF will present unique requirements that industry may be able to address within the framework presented for the future. The Marine Corps is ready and eager to team with industry to address these challenges.

Brigadier General Amos graduated from the University of Idaho in 1970. He was designated a Naval Aviator in 1971 and has held a variety of operational and staff assignments since 1972. He is currently serving as the Assistant Deputy Commandant for Aviation (Code AA), HQMC, Washington, D.C. effective June 29, 2000. Brigadier General Amos is a graduate of the Armed Forces Staff College, Norfolk, VA and the Air War College, Maxwell AFB, Alabama. He may be reached at 703.614.2380 or amosjf@hqmc.usmc.mil.

A Short History of Aircraft Survivability

by Dr. Richard P. Hallion

The subject of survivability is one of critical concern to many disciplines, whether military or civil. It is of particular concern when one is operating in an innately hostile environment—particularly above the surface in an airplane or spacecraft. There have been notable examples where fault-intolerant design has led to failure, some with quite disastrous and tragic outcomes. One only need look at a few of these to get a sense of the larger problem—

- The unanticipated danger of explosive decompression which crippled the De Havilland Comet jetliner program and fatally set back what had been, to that time, Britain's international leadership in jet transport design.
- The unforgiving design of the Space Shuttle's solid-fuel boosters, which led to the loss of Challenger in 1986, delaying--and nearly terminating--the entire Space Shuttle program.

So it should come as no surprise that survivability is a demanding and implacable field of inquiry, and that it is, of course, inherently related to broader areas of study such as human factors and safety, modern technological development, and military concepts of operations.

In many ways the history of aircraft development through the years has really been the quest for the survivable airplane. In this article, I would like to review the military experience with aircraft survivability, beginning with the end of the Vietnam war.

Vietnam and the experience of the 1973 Arab-Israeli war clearly rattled the confidence of those who felt that high-performance military aircraft were relatively invulnerable to enemy defenses simply on the basis of high transonic or supersonic dash speed, or because of perceived pilot excellence. Both of these translated into technological and cultural hubris and numerous aircrew paid the price for such delusions. Over the first four days of the 1973 Arab-Israeli war, Israel lost 60 fighter and attack aircraft, equating to approximately 19 percent of its prewar combat aircraft inventory. Strike formations operating over the Golan Heights encountered upwards of fifty SAMs airborne, and the "layered" nature of Egyptian and Syrian defenses—SA-6s, SA-2s, SA-7 MANPADS, and the infamous ZSU-23-4 gun carriage-posed particular challenges. Like Vietnam, the war also illustrated the synergy between missiles and guns—evading missiles took aircraft to lower altitudes, rendering them more vulnerable to MANPADS and light antiaircraft fire. By war's end, Israel had lost approximately 109 aircraft, representing fully 35 percent of its prewar strength, in just nineteen days of combat. So effective was the SA-7, that U.S. Navy logistical establishments were stripped of A-4 tail sections that were then shipped via C-5 airlifters to Israel to replace those damaged by the nasty little heat-seeker. Truly, as Israeli General Chaim Herzog later wrote, *"The Israeli Air Force fought a desperate battle, flying into the teeth of one of the most concentrated missile systems in the world."*[1]

Coming on the heels of Vietnam, the Arab-Israeli war of 1973 clearly indicated a new "normative" form of air warfare-attempting to deny an enemy the freedom to operate his air force by inflicting air denial via missile forces and, to a lesser extent, classic air forces. Key to this strategy was the provision of good command and control, linked to early warning and fire control radars, some of which might be in airborne platforms. The American response—not so much fully focused on what to achieve, but adopting a flexible attitude that examined technological options and then adapted them to military need—was increased emphasis on standoff precision attack, standoff jamming, updated Wild Weasel airplanes based on the F-4 Phantom, and, finally, the low observables revolution. Low observables was first demonstrated with the Lockheed XST Have Blue demonstrator in 1977-1978. Have Blue and another demonstrator, the Northrop Tacit Blue vehicle, produced a knowledge base that translated low observables from an interesting if largely theoretical field to inquiry

into practical weapons systems. The first operational stealth aircraft—if stealth is defined as the vehicle's primary design requirement—was the Lockheed F-117A, which entered frontline service in the fall of 1983. With the advent of stealth, aircraft and force survivability entered a new era.

That new era was dramatically demonstrated not quite a decade ago, in January-February of 1991 in the skies over Kuwait and Iraq, in Operation *Desert Storm*. Much has been written of *Desert Storm* and there is no need for an extensive treatment of it here. But it is worth noting that *Desert Storm* confirmed some of the major transformations that were occurring in military power—what the Air Force, in its strategic planning framework issued in the summer of 1991 had termed "Global Reach-Global Power"—and the technological investment that the nation had made since Vietnam.

As we all recall, SEAD and stealth worked. On opening night, 785 attackers, supported by 478 SEAD, sweep, and escort aircraft (an escort-to-attacker ratio of 0.61:1) using techniques ranging from jamming to drones, decoys, and direct anti-radar missile attack, struck approximately 144 targets with 370 aimpoints and shattered Iraq's military infrastructure, at the cost of one SEAD airplane lost. This record—a loss rate of .00079, or 0.79 aircraft lost per 1,000 sorties—should be compared to the March 1944 RAF night raid on Nuremberg, where a roughly equivalent sized force of bombers experienced a loss rate of 0.13889, or 139 airplanes lost per 1,000 sorties basically attacking a single aim point.

But the real lesson for the future was the value of stealth. On one attack against one Iraqi target, Shiba airfield, having three aimpoints, eight strike airplanes (four A-6Es and four Saudi Tornadoes) were screened by four F-4G Wild Weasels, five EA-6B jammers, four F/A-18s for combat air patrol, three drones, and no less than 17 F/A-18 Harm antiradar missile shooters. Thus, the ratio of escort to attacker was 4:1, consistent with previous experience virtually back to the dawn of military air attack operations. At the same time, just by themselves, 21 F-117s were attacking 38 even more heavily defended aimpoints by themselves. In another case, eight F-117s could strike sixteen different aimpoints by themselves, offsetting a package of sixty nonstealthy aircraft—32 bomb-droppers, 16 air superiority escorts, four jammers, and eight Wild Weasels.[2]

The Gulf War, of course, was not fought without loss. Table 1 enumerates coalition air losses during the war.[3] As can be seen, the risk of combat damage and loss threatened virtually all combat aircraft used in the Gulf. Over the length of the conflict, the coalition lost 38

Table 1. Desert Storm Coalition Aircraft Attrition

Service	Type	Sorties	Damaged	Damaged/1000 Sorties	Lost	Lost/1,000 Sorties
USAF	A/OA-10A	8,620	14	1.6	6	0.7
	AC-130	101	1	9.9	1	9.9
	B-52G	1,741	5	2.9	0	0.0
	EF-111A	1,105	0	0.0	1	0.9
	F-111F	2,420	3	1.2	0	0.0
	F-15C	5,674	1	0.2	0	0.0
	F-15E	2,142	0	0.0	2	0.9
	F-16	13,066	4	0.3	3	0.2
	F-4G	2,678	0	0.0	1	0.4
USN/USMC	A-6E	5,593	5	0.9	3	0.5
	F-14	3,916	0	0.0	1	0.3
	F/A-18	9,250	8	0.9	2	0.2
	AV-8B	3,349	2	0.6	5	1.5
	OV-10	482	0	0.0	2	4.1
Coalition	A-4	651	0	0.0	1	1.5
	F-5	1,129	0	0.0	1	0.9
	Jaguar	571	4	7.0	0	0.0
	Tornado	2,482	1	0.4	9	3.6

fixed-wing aircraft to enemy defenses, only one of which possibly fell to an enemy aircraft. The U.S. Air Force's loss rate—approximately .25 of one percent—was far below the prewar "optimistic" estimates of half of one percent and the pessimistic estimate of 2 to 4 percent (or even, in some extreme cases, claims the coalition might lose upwards of 10 percent) due to enemy action. In part, loss rates were low due to intensive SEAD and a general limitation of operations below 15,000 feet. The war revealed two peak loss periods—the first week, in which approximately half of all losses occurred, and the last week, when aircraft were operating in closer proximity to the ground and, hence, enemy defenses. Over the last ten days of the war, the coalition averaged a plane lost every day.[4]

Ground attack aircraft, not surprisingly, suffered the greatest attrition. The Air Force lost an AC-130 gunship to enemy ground fire when it was caught in daylight over hostile territory, 25 percent of those then in theater, and an average loss rate of nearly 10 per 1,000 sorties—clearly unacceptable. The Marines lost two OV-10 forward air controller aircraft to ground fire, 11 percent of those deployed in theater, and an average of 4 per 1,000 sorties. Despite their rugged design and extensive preservice survivability testing, A-10's experienced high losses. In fact, their losses ramped upwards so sharply towards the end of the war as the plane was used increasingly at low altitudes that the joint force air component commander, General Charles Horner, sharply downscaled A-10 operations from that point onwards. Overall, five were lost and a sixth so badly damaged as to be unrepairable, an overall 4 percent loss rate for the A-10 force deployed in theater, and an average loss rate of 0.7 aircraft per 1,000 sorties. After the war, the official DoD report to Congress concluded *"While the survivability features of the A-10 are good, future aircraft should be designed with higher performance to reduce susceptibility to damage while maintaining low vulnerability."*[5]

The V/STOL Marine AV-8B suffered five losses, representing six percent of those in theater, apparently to the high heat signature of its vectored thrust engine attracting heat-seeking missiles. Iraqi SAMs claimed two F-15E Eagle strike aircraft early in the war, and while no more Eagles were lost during *Desert Storm*, these two aircraft themselves represented four percent of the total deployed Strike Eagle force, and a loss rate of 0.9 per 1,000 sorties. Early in the war, low-flying Tornadoes took surprisingly high losses as a result of tactics, heat signature, and the visible signature of the airplanes' pink desert camouflage at night. Overall nine were lost; RAF Tornado losses represented 13 percent of the RAF Tornado force then serving in the Gulf.[6] These examples indicate how, in an era of relatively small deployed overseas forces, even a few losses can erode a significant portion of a nation's combat potential, particularly if those losses continue over time.

This discussion should not imply that, somehow, the Gulf War was a costly war, for it was not—but it was certainly not a risk-free or blood-free conflict. The experience with air warfare since that time—notably the *Deliberate Force* and *Allied Force* Balkan air campaigns of the mid-and-late 1990's—took losses to an even lower level. But these conflicts as well were not, certainly, risk-free exercises. In *Deliberate Force*, the sole aircraft lost was a Mirage hit by a Serb heat-seeking missile. In Allied Force, an F-16 and F-117 fell victim to Serb SAM defenses. The lessons here--as with the well-publicized shoot-down of an F-16 over Bosnia by an SA-6 earlier--is that in the missile era, constant vigilance is the watchword for successful air operations. Low-altitude operations are particularly dangerous, and the unwary or unfortunate may all too quickly find themselves victims. In these circumstances, air commanders must exercise aggressive SEAD and intimidation of opponents to both best protect their forces and ensure fulfillment of overall national security objectives. A notable and successful example of where this was done in a particularly high-tempo and demanding environment was by the air commanders and airmen participating in Operation *Northern Watch* in 1998-1999.

Today in an era that is increasingly dominated by the linkage of intelligence, surveillance, and reconnaissance (ISR) assets to precision engagement systems, the Air Force speaks of entering an era of "Global Vigilance, Reach, and Power." The accomplishments in aerospace power projection through the years, and, in particular since the time of the Gulf War on through Bosnia and Kosovo, clearly indicate that we have entered an era of

warfare in which the surface warrior is increasingly constrained and, indeed, controlled, by what is happening above and below the surface. For centuries, armies and, to a lesser degree, navies, were built on an inherent attrition model of war. That model of war demanded mass, as the individual capabilities of any one soldier or sailor, or even any one small unit or small vessel, were quite limited. Today that is not the case.

We have, in fact, fulfilled the vision of the great military strategist and thinker, Major General J. F. C. Fuller, who wrote in 1945 that it is range *"which dominates the fight."* He stated further, *"The weapon of superior reach or range should be looked upon as the fulcrum of combined tactics. Thus, should a group of fighters be armed with bows, spears, and swords, it is around the arrow that tactics should be shaped; if with cannon, muskets and pikes, then around the cannon; and if with aircraft, artillery, and rifles, then around the airplane."*[7] But that fact hints at the survivability battles yet to come. The history of military aviation has witnessed a seesaw battle between the offensive power of the airplane and the defensive snap of its victims. In an era—

- When the size of deployed coalition air power forces is likely to shrink,
- When future aircraft production runs may be measured in dozens rather than several hundred or several thousand,
- When potential opponents will have little difficulty in acquiring advanced Flanker-equivalent threat aircraft and the weapons systems for those aircraft to hold air and surface targets hostage,
- When the SA-10 equivalent weapon will undoubtedly become the common currency of air defense in much the same fashion that the SA-2 was in the '60's and the SA-6 in the '70's and onwards, and
- When other weapon options-for example, portable or mobile laser weapons, or even hypersonic missiles-can be expected to proliferate, together with increasingly sophisticated architectures for commanding and controlling all of these kinds of forces and capabilities,

The challenge for those having responsibility to ensure the survivability of our joint service aerospace forces is, if anything, even more demanding than it has been in the past.

In 1971, DoD formed the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS). Today the JTCG/AS is chartered by the Joint Aeronautical Commanders Group (JACG) and funded by the OSD's Director of Operational Test and Evaluation/Live Fire Test and Evaluation Office. The JTCG/AS's mission *"is to be an advocate for aircraft combat survivability in the Defense Department and to promote cross-service cooperation in the combat survivability design discipline."* This important organization has played a keystone role in the evolution and thinking of survivability and survivability studies in the years since Vietnam.

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Endnotes

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2. For more on this, see the author's *Storm Over Iraq: Air Power and the Gulf War* (Washington, D.C.: Smithsonian Institution Press, 1992), pp. 248-250, and Bowie, *Untying the Bloody Scarf*, pp. 13-17.
3. GWAPS, v. 5, Table 205, p. 651. I have combined some of the data and corrected other data, notably the Tornado statistics. Missing from this listing is RAF Buccaneer sorties, to "buddy lase" for Tornado strike airplanes. But, in any case, no Buccaneers were damaged or lost in the war.
4. U.S. Dept. of Defense, *Conduct of the Persian Gulf War: Final Report to Congress* (Washington, D.C.: DoD, April 1992), pp. 178-179.
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JASMAN

The Joint Aircraft Survivability to Man-Portable Air Defense Systems Joint Feasibility Study

by Dr. Kristina Langer

We must hold our minds alert and receptive to the application of unglimpsed methods and weapons; the next war will be won in the future, not in the past. We must go on, or we will go under.

—General of the Army Douglas McArthur, 1931

The threat to US aircraft from hand-held infrared (IR) surface-to-air missiles (SAMs) is not new. For nearly three decades American aviators have served their country under peril of these man-portable air defense systems (MANPADS). Beginning with the introduction of the Russian-built SA-7 into the Southeast Asia (SEA) conflict, and continuing on through recent experiences in Kosovo, the threat of MANPADS has plagued nearly every US military operation. And we have paid a significant price in men and materiel. Since 1972, more US aircraft have been lost to IR SAMs than to all other threats combined.

Damage to an A-10 wing from a MANPADS impact during Operation Desert Storm.

The preferred approach to countering the MANPADS menace has been technology. Starting with decoy flares fired from Veri pistols during the SEA conflict, counter-SAM technological advances have followed analogous threat advances through increasingly sophisticated self-protection systems. Active and passive hit avoidance measures have historically been the focus, although recent developmental efforts are taking a closer look at hit tolerance methods as well. The drawbacks to purely technological improvements, however, are time and money. As MANPADS continue to evolve both in lethality and ease of acquisition, the lengthy development and production cycles, along with fiscal constraints associated with fielding new technologies have led to very real near-term deficiencies in our abilities to effectively counter this threat.

The Office of the Secretary of Defense (OSD) has recently activated a study that is investigating the efficacy of a somewhat different solution approach. Given the gap between current needs and future capabilities, what is the potential for mitigating MANPADS threats through the innovative employment of currently available capabilities? Is new technology the only feasible solution, or can changes to employed tactics, techniques, and procedures (TTP) and concepts of operations (CONOPS) help mitigate the threat in the near term? These issues are the focus of OSD's Joint Aircraft Survivability to MANPADS (JASMAN) Joint Feasibility Study (JFS) whose goal is to investigate the necessity and technical feasibility of conducting a Joint Test and Evaluation (JT&E) program geared toward joint, non-acquisition solutions to the MANPADS problem.

The Joint Test and Evaluation (JT&E) program was established by Congress to evaluate concepts and address needs and issues that occur in joint military environments. The JT&E program integrates the expertise of the Defense T&E community and the expertise of our warfighters to investigate and solve complex joint operational problems. The program applies rigorous test and evaluation methodologies to provide timely solutions applicable to the joint military community. As specified in DoD Directive 5010.41, Office of the

Undersecretary of Defense (Acquisition, Technology, and Logistics) has overall program responsibility. All joint test directors report to Mr. Richard Lockhart, the Deputy Director, Developmental Test and Evaluation (DD,DT&E). DD,DT&E provides critical liaison within OSD and promotes each JT&E program's legacy products to the warfighter.

Through the expertise of the JASMAN Joint Warfighter Advisory Group (JWAG) and with technical assistance from the JTCG/AS, the study team has identified three top-level, warfighter-critical, operational issues relative to aircraft-MANPADS interactions—

Issue 1: How severe is the problem?

How effective are currently employed TTPs and CONOPS in countering threat IR MANPADS during joint operational air missions conducted in the low to mid-altitude regime?

Issue 2: How effective are potential mitigation techniques?

What changes in joint and Service TTPs and CONOPS improve effectiveness of joint operational air missions in the presence of threat IR MANPADS?

Issue 3: How can the process be improved?

How can test methodologies (processes) be improved to better characterize effects of threat IR MANPADS on the effectiveness of joint operational air missions?

The challenge currently underway is to develop a JT&E test concept that will resolve these issues to satisfy warfighter and flag officer requirements, while adhering to OSD's specified time and budget constraints. To meet these requirements, the JFS is outlining a MANPADS-specific test process (Issue 3) which will be used to test and evaluate joint, counter-SAM TTPs and CONOPS. Both currently employed concepts (Issue 1) and operator-developed enhanced procedures (Issue 2) will be addressed in realistic tactical environments, including airfield and target area scenarios. Counter-SAM TTPs and CONOPS under study include maneuvers; innovative employment of equipment and personnel (including current aircraft self-protection measures); and airfield-related courses of action.

The current JASMAN plan is focusing on joint, counter-SAM TTPs and CONOPS that are applicable across classes of aircraft: heavies and high-value air assets; fighter/attack platforms; and helicopters. Within and across each of these classes, a combination of digital modeling, hardware-in the-loop simulation, and live testing will be used to analyze, test, and evaluate the effectiveness of both currently employed TTPs/CONOPS and warfighter-developed alternative procedures. The test process itself is also considered a "test article" so that upon conclusion of the test program a validated, operator-approved process can be used to evaluate additional platforms, threats, and future improvements to TTPs/CONOPS.

The JASMAN Joint Feasibility Study is ongoing, with a target completion date of Sep 01. A chartering decision (to determine whether to proceed into the test phase) will be made in August by OSD's JT&E Senior Advisory Council, a board of senior (Flag and Senior Executive Service) leaders from OSD, the Joint Staff, Joint Forces Command, the Services, and Defense Field Activities. Additional information can soon be found at the JASMAN Web site: http://www.jasman.wpafb.af.mil, or by contacting the JASMAN Feasibility Study Director (Ralph Lauzze) at 937.255.6823 x 233 (DSN 785), ralph.lauzze@wpafb.af.mil or the JASMAN Technical Director (Kristina Langer) at 937.255.6302 x224 (DSN 785), kristina.langer@wpafb.af.mil.

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Michael "Mike" Meyers

by Dale B. Atkinson

Michael (Mike) Meyers has been involved in major survivability programs since 1965 and has become one of the top vulnerability reduction engineers in the country through his efforts on the F-4, F-15, F-18, and other aircraft.

Mike grew up in Saint Louis, Missouri and received his B.S. in Electrical Engineering from Washington University in 1960. After graduation Mike went to work for the Naval Research Laboratory (NRL) Radio Physics Branch developing frequency synthesizers. During this time he married his wife Lynn and in February 1962 returned to St. Louis to work for the McDonnell Aircraft Company (The Boeing Company) where he has worked since that time.

As a member of the Operations Analysis Department, Mike was involved in a variety of projects the first few years including hypersonic aircraft concepts, tactical reconnaissance and nuclear weapons effects. In 1965 he was assigned to review early reports of Navy and Air Force combat losses in Vietnam. Mike initiated the first Boeing vulnerability assessments of the F-4 and RF-101 aircraft to identify the principal contributors to losses. In 1966-67, Mike participated in UASF Project 5105 to recommend vulnerability reduction concepts that could be retrofitted on F/RF-4C/D and RF-101 aircraft due to the losses being experienced in Southeast Asia. The results of the study identified self sealing tanks, internal foam explosion suppression, separation and redundancy of hydraulics and fuel lines, and armor for the stabilator actuator as high payoff modifications that would reduce combat losses of crews and aircraft. These fixes were incorporated in production F-4E aircraft starting in 1969.

In 1969, Mike was assigned to the Vulnerability Team for the USAF F-15. Vulnerability reduction was a primary element since the F-15 was the first Air Force aircraft to have a detailed design specification. Using analytical methods, and supported by a series of gunfire tests at Boeing and Air Force ranges, Mike participated in the development of gross voided foam for explosion protection that saved considerable fuel volume and reduced weight over conventional protection systems. Dry bay foam, recommended by Mike for F-15 fire suppression in voids around fuel tanks, was successfully tested by the Air Force and later incorporated for the F-15E configuration. Working with designers from the beginning, significant vulnerable area reduction was achieved by evaluating the installation of systems and maximizing redundancy and separation of flight critical components. Although the F-15 is a large aircraft, its vulnerable area is small compared to its presented area due to Mike's efforts. During this time, Mike developed penetration equations for various F-15 materials and component damage probabilities based on available test data and engineering judgement to improve the accuracy of the vulnerability analysis methodology used on the F-15. Working with the Ballistics Research Laboratory (now the Army Research Laboratory) at Aberdeen, Maryland, Mike also developed a method of estimating F-15 internal and external blast kill envelopes.

In 1975, Mike was selected to lead the Vulnerability Team for the Navy F/A-18A/B Program. From the proposal phase through full-scale development, he developed and applied several innovative analysis techniques to meet the vulnerability requirements for the first Navy aircraft with a detailed survivability specification. The analysis included evaluations of protection systems to reduce vulnerable areas and provided engagement results in terms of loss rates during combat simulations. Life cycle cost effectiveness analysis was applied in the decision making process. As a result, a damage control system was developed to minimize fuel ingestion of the engine(s) and incorporation of wing tank foam with an extended life was provided. Dry bay foam was installed for fire suppression and reservoir level sensing was included to provide hydraulic system damage isolation without complete system loss. Joint live fire tests conducted by the Navy more than 10 years later verified the earlier analysis showing the extent of survivability improvement for the F/A-18 Hornet. In addition, *Desert Storm* proved the F/A-

18 Hornet's survivability in combat. For example, four F-18 Hornets hit by MANPADS during that conflict were quickly returned to combat, three within 24 hours and the fourth within 48 hours.

During the early 1980s, Mike was the program manager for two studies for NRL. These programs examined the effect on aircraft, aircrew and sensors for exposure to a variety of existing and postulated laser threats. These reports, called "Survivability and Hardening of Tactical Aircraft in a Laser Incurred Threat Environment (SHOTLITE)" were considered by NRL to be the first analyses to quantify the effectiveness of lasers in a battlefield environment.

During the next 5 years Mike worked on the Navy's A-12 program, leading the joint McDonnell Douglas/ General Dynamics (now Boeing St. Louis/Lockheed Fort Worth) Vulnerability Reduction Team in developing the first active dry bay fire suppression system included in the design of an aircraft. Halon was employed as the extinguishing agent and was successfully gunfire tested at the Navy's China Lake facility, verifying the vulnerability analysis conducted by Mike's team. The A-12 was required to meet the new Live Fire Test Law, and Mike, in conjunction with the Navy, originated the A-12 Live Fire Test Plan using a building block approach that is still in use today on other aircraft.

As the Vulnerability Team Leader on the F/A-18E/F program since 1992, Mike directed Boeing efforts toward new technology in the fire/explosion suppression arena. Development of a gas generator system for fire protection in drybays began with Mike's early program analysis and life cycle cost trade-off study. Development and Live Fire Testing by the Naval Air Warfare Center Weapons Division at China Lake have demonstrated the capability to replace Halon (an ozone depleting agent) and simultaneously reduce weight and vulnerability compared to earlier designs. The F/A-18E/F is the first aircraft to develop and employ this system. Working with the Integrated Product Teams at Boeing, Northrop Grumman, and the Navy, the Vulnerability Team has integrated "lessons learned" from the F/A-18A/B/C/D to reduce vulnerability on the F/A-18E/F. Examples are increased redundancy and separation of hydraulic, flight control, and electrical systems. Improved protection for engine fuel ingestion was accomplished and verified under the Live Fire Test program.

Mike's years at Boeing have been dedicated to the development of vulnerability prediction tools for specific design configurations, working with design teams to develop vulnerability reduction solutions, and conducting tests to verify design concepts. These accomplishments made use of an analytic approach using JTCG/AS and JTCG/ME computer programs and established realistic damage probabilities for various aircraft subsystems and components. One of these programs was the Computer Vulnerability Area and Repair Time (COVART) model first used in aircraft projectile and fragment evaluations in 1976. Although this model has seen many changes over the years, it is still the benchmark for aircraft vulnerable area assessment. Through his expert knowledge of the survivability area, ability to conduct realistic trade studies, knowledge of the total design, and special insight into which survivability features provide the most payoff to

F/A-18E/F participants (left to right) Chris Fischer, Tony Tainatango, Grayson Goodrich, Charlene Plumb, Andy Hesketh, Mike Meyers, John Aldrich, and Mikal Gray.

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Aviation Survivability Equipment Overview (ASE)

by Dr. Steven Messervy and Mr. Steven Stegman

PM, AES Mission

The mission of the Aviation Electronic Systems (AES) Project Office is to develop a family of survivability enhancement systems designed to counter threats in the infrared (IR), radio frequency (RF) and laser guided missile system arenas. In addition, the Project Office is responsible for development of Aircrew Integrated Systems and Aviation Survivability Life Support Equipment for aviators.

The AES Project Office is responsible for all Army ASE and currently manages five ASE systems from its offices at Redstone Arsenal, Alabama. These include three currently fielded systems: the AVR-2A(V) Laser Detecting Set; the AN/APR-39A Radar Warning Receiver; (transitioned to CECOM in Sep 00)and the Aircraft Survivability Equipment Trainer (ASET) IV. Developmental systems include the AN/ALQ-211 Suite of Integrated Radio Frequency Countermeasures (SIRFC) and the AN/ALQ-212 Advanced Threat Infrared Countermeasures/Common Missile Warning System (ATIRCM/CMWS) system.

ATIRCM/CMWS, AN/ALQ-212

The Advanced Threat Infrared Countermeasures (ATIRCM) is known as the AN/ALQ-212 and includes as a component the AN/AAR-57 Common Missile Warning System (CMWS). ATIRCM/CMWS is being developed to enhance aviation survivability against a growing number of infrared guided threats. The ATIRCM/CMWS system provide automatic, passive missile detection, threat type declaration, crew warning, false alarm suppression, and cues to other on-board systems such as countermeasure decoy dispensers. For rotary wing platforms, ATIRCM provides active directional countermeasures via a laser, an arc lamp, and an Improved Countermeasures Dispenser (ICMD).

ATIRCM system.

ATIRCM/CMWS has six major components: Electro-Optic Missile Sensor (EOMS), Electronic Control Unit, Infrared Jam Head, Jam Head Control Unit, Infrared Jam Laser and the Improved Countermeasure Dispenser (ICMD). The ICMD consists of one ALE-47 sequencer with two dispensers capable of automatically sensing the payloads present.

ATIRCM/CMWS combines the functions of a missile detector, IR jammer, and decoy dispenser to permit more effective countermeasures against a greater number of threats. ATIRCM/CMWS is being built using a modular concept to allow tailoring of the system configuration to each aircraft type.

The first fully integrated ATIRCM/CMWS EMD system was demonstrated by the prime contractor, Sanders, a Lockheed Martin Company, (now BAE SYSTEMS of North America) in April 1998 and Contractor Qualification Testing (CQT) began in July 1998. During CQT, the system is subjected to a series of tests designed to prove its operation under extreme combat environmental conditions. Air vehicle integration on the Army EH-MH-60 began earlier in 1998 and continued with sled and electromagnetic vulnerability testing in 2000. Engineering and Manufacturing Development (EMD) system deliveries continue through the first quarter of FY01.

Developmental test (DT), beginning in FY01, will consist of potential false alarm source (PFAS) testing, hardware-in-the-loop (HITL) tests, and dynamic target missile firings. The USAF 46th Test Squadron (TS), Eglin Air Force Base, FL will provide developmental test analysis to support Milestone III.

Developmental Test and Multi-Service Operational Test (OT) and Evaluation, consisting of Combined DT/

OT and Dedicated OT, will be used to provide a combined System Assessment (SA) Report as input to Low Rate Initial Production (LRIP) and Milestone III decisions. Combined DT/OT will consist of two parts. The first part includes Cable Target Missile Firings (CTMF), Captive Seeker Tests, and sled tests will provide all data requirements necessary for the evaluation to support the LRIP decision. The second part includes CMTF Part 2 which, together with OT, will support the production decision.

AH-64 Apache suspended in anechoic chamber for testing.

SIRFC, AN/ALQ-211

The Suite of Integrated Radio Frequency Countermeasures (SIRFC), AN/ALQ-211, is an Acquisition Category (ACAT) III program currently in the EMD phase. SIRFC will replace the APR-39 and the AN/ALQ-136 pulse jammer and will enhance aircraft survivability against a growing worldwide threat of RF guided systems. SIRFC provides protection against radar guided Anti-Aircraft Artillery, Surface to Air Missiles (SAM) and Airborne-Intercept (AI) for all Army Aviation to include, AH-64 and SOA (MH60/47), UH-60 and CH-47 aircraft. The SIRFC provides situational awareness, sensor fusion, resource management, target identification, target location, target cuing and preemptive and terminal mode Electronic Countermeasures (ECM) against fire control radars and semiactive missiles for both air-to-air and surface to air weapons. These threats include pulse radar, pulse Doppler and continuous wave radars in a wide operational frequency range.

The SIRFC is comprised of a receiver processor, a transmitter, an advanced countermeasures module and an antenna group. Central to the receiver/processor and transmitter units are standard electronic module, size E (SEM-E) cards that can be used to tailor the SIRFC for different functions such as receiver-only or a full-up warning and countermeasures system. Additionally, SIRFC will provide sensor fusion technology, correlating data from the ATIRCM/CMWS and AVR-2A systems.

The SIRFC program was restructured early in fiscal year 2000, extending the EMD phase of the system to a LRIP decision in the second quarter of FY02 and a production decision (Milestone III) in the second quarter of FY03. A key component of the program restructure is a ten-block software delivery schedule that utilizes an incremental approach. Radar Warning Receiver (RWR) and Electronic Countermeasures functionality is added in the first seven blocks, while the last three blocks are designed to support software changes and maintenance resulting from SIRFC system and flight testing. As each software block is released, independent government testing assesses the system performance.

The SIRFC test strategy is based on two aviation platforms, the AH-64D Apache and the special operations CV-22 platform. System Assessment is a cooperative effort between the Army Test and Evaluation Command and the Air Force Operational Test and Evaluation Command. Developmental and limited user testing on the AH-64D platform will provide an operational assessment to support an LRIP decision and will allow SIRFC to be transitioned to a production Apache longbow with a qualified A-kit. SIRFC Initial Operational Test and Evaluation is to be conducted on the CV-22.

The RWR technology of the SIRFC system was selected for insertion into the RAH-66 Comanche Armed Reconnaissance Helicopter,

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The next revolution in survivability will be to get the pilot out of the aircraft altogether.

First to appear on the battlefield were the unpiloted reconnaissance vehicles—Pioneer, Predator, and Hunter, developed by DARPA and others. The DARPA High Altitude and Endurance Unmanned Air Vehicle Tier II Minus, otherwise known as Global Hawk, is about to enter the inventory. Global Hawk can self-deploy to any battlefield on earth, and stay on station for over 24 hours nonstop. This kind of long-duration, focused presence enables superior battlefield surveillance and reduces the burden on manned reconnaissance platform aircrews. DARPA is currently working on much smaller unmanned air vehicles that are launched from, controlled by, and provide their information directly to small units on the battlefield. They may even be able to fly under tree canopies, to find hidden forces, or to perch, for long-term observation.

The next step in the revolution is to transfer combat missions to unpiloted aircraft. One of the most hazardous combat missions is the Suppression of Enemy Air Defenses (SEAD). The DARPA Unmanned Combat Air Vehicle (UCAV) is a revolutionary new tactical air power, which will perform both preemptive and reactive SEAD missions (see Figure 3). UCAV will provide a persistent all-weather strike capability, which augments the manned force structure. It has a highly survivable design for first-day penetration. In addition to attacking advanced integrated air defense systems, it is also suitable for engaging time critical targets at any phase of the conflict.

The first UCAV demonstration air vehicle was recently rolled out. It is a high-subsonic, all-electric aircraft for medium-to-high altitude operation. Its survivability suite will include affordable stealth to the next level. It has a gross weight of 15,000 pounds (7,500 pounds empty). It will have a 500-1,000 mile mission radius while carrying a payload from 1,000 to 3,000 pounds, selected from a wide range of current and advanced weapons. It will carry electronic signals monitoring (ESM) and on-board synthetic aperture radar to develop real-time SEAD targeting solutions.

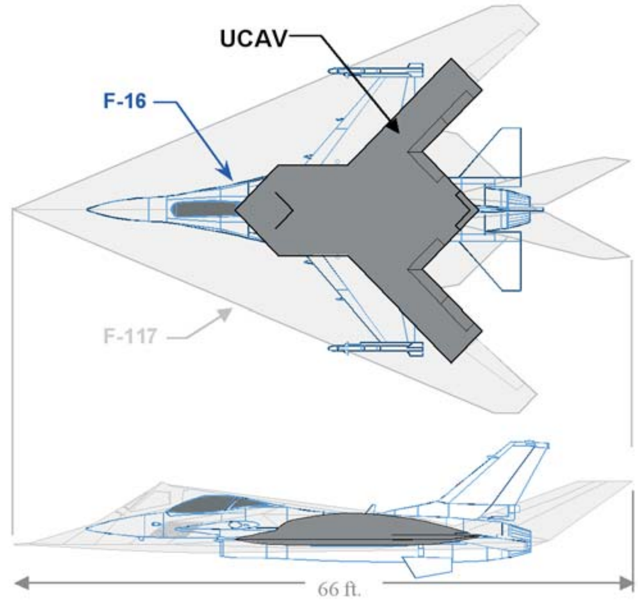

Figure 3. The small size of the UCAV aircraft will increase its survivability. Since there is no aircrew, a high payload fraction can be maintained. With an empty weight of 7,500 pounds, UCAV will be able to carry 1,000-3,000 pounds of payload.

UCAV is another example of how tactics and technology must be considered together to get real gains. Tactics for accomplishing the SEAD mission were being considered and modeled during the preliminary design phase. The use of small precision bombs allows having a smaller aircraft—and a smaller aircraft means better stealth, and higher survivability.

In addition to its revolutionary implications for strike warfare, UCAV represents a new paradigm in aircraft affordability. It is being designed for greatly reduced acquisition costs (less than one-third the cost of a Joint Strike Fighter). It is expected to have operation and sustainment costs less than one-quarter of those for a manned aircraft. It enables maintaining a mixed force structure. A program for developing a Navy variant of UCAV suitable for carrier flight operations is in its initial stages. UCAV-N will support naval concepts of operations with missions including deep strike, SEAD, and battlefield surveillance.

Global Awareness

There are many other DARPA programs that will have positive impacts on survivability. The many information superiority programs will provide superior battlefield

awareness, which can only help with survivability. From advanced tactical networks, to combat identification systems, to foliage-penetrating sensors, to compact lasers for infrared countermeasures, to robust navigation systems, DARPA is moving to leverage the latest technological advances while denying the same advantages to adversaries.

Another revolutionary concept is the idea of continuous global awareness. Imagine a system that gave the excellent moving target indication performance of JSTARS (another past DARPA success story), but continuously everywhere on the globe. Now targets could be tracked "from birth to death," and real-time targeting information provided to strike packages enroute. High-threat, time-critical targets (such as surface-to-air missile launchers) could no longer take advantage of mobility to hide from surveillance and reconnaissance assets.

To get this span of coverage, the mission must clearly be performed from space; to make it all-weather, the sensor must be radar; to make it affordable, the spacecraft must be in low earth orbit and break new ground in military spacecraft affordability. Under the Discoverer II program, DARPA contractors developed lightweight active electronically steerable antennas suitable for space-based radar that can meet the stringent price requirement. Hopefully in the future, the nation will choose to invest in this radical new capability. It too will bring a quantum improvement in survivability, as have the other DARPA-initiated revolutions.

Dr. Whelan is Director of DARPA's Tactical Technology Office. During his career, he has contributed to numerous radar and aerospace programs, including the design of the B-2 Spirit. At DARPA, his office engages in high-risk, high-payoff advanced military research, emphasizing the "system" and "subsystem" approach to the development of aerospace, land, and global awareness systems, as well as embedded processors and control technologies. Dr. Whelan earned a B.A. in physics from the University of California at San Diego in 1977 and a Ph.D. in Physics from the University of California at Los Angeles in 1983. He is a member of the American Physical Society, the IEEE, and the AIAA.

Editor's Note: Dr. Whelan recently retired from DARPA. He is now the Vice President and Chief Technology Officer, Boeing Space and Communications Group, Seal Beach, California. He may be reached at 562.797.3100.

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overall mission effectiveness, the Navy's F/A-18 Super Hornet is one of the most survivable aircraft of its era. Although it is 25 percent larger than the original Hornet, its vulnerable area is smaller, which is a significant accomplishment.

Mike has made major contributions to the overall Survivability community by serving as a member of various Government/Industry Advisory Teams for the JTCG/AS, SURVIAC, and others over the years. In 1995 he was selected to be an Executive Board member of the National Defense Industrial Association's Combat Survivability Division. Mike has also served as a member of the American Institute of Aeronautics and Astronautics Survivability Technical Committee. In 1998 Mike was an industry representative on the Program Advisory Committee for the JTCG/AS project on "Reduction of Aircraft Vulnerability to Man-Portable Air Defense Systems." At the invitation of Distinguished Professor Robert E. Ball, Mike has been a guest lecturer at the Naval Postgraduate School course on Aircraft Survivability for more than 20 years.

As a result of being a recognized expert in aircraft vulnerability and live fire testing, Mike was selected a Boeing Technical Fellow in 1999. He has been consulted for various Boeing in-house projects including the C-17, V-22, and currently for the JSF program. He continues to improve Boeing's vulnerability analysis techniques and to train others in his area of expertise. His career contributions will positively impact the survivability community for many years to come. Mike says *"The success we have had in reducing aircraft vulnerability over the years, is a result of hard work by many dedicated people at Boeing, subcontractors and our government counterparts that have supported my efforts."* I have known and worked with Mike for over 35 years and am happy to present him as one of the survivability pioneers who has made outstanding contributions to the survivability area and the warfighters over many years.

Mr. Dale B. Atkinson may be reached at dba@erols.com.

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currently under development. ITT Avionics of Clifton, New Jersey will provide Comanche RWR functionality.

AN/AVR-2A

The AN/AVR-2A Laser Detecting Set is a passive laser warning system which receives, processes and displays threat information resulting from aircraft illumination by threat laser aided weapons. The AVR-2A Laser detecting Set consists of four sensors mounted on the aircraft surface plus one internally mounted central interface unit.

The AVR-2A is currently installed on U.S. Army and Navy aircraft including: OH-64A/D, OH-58D, MH-47E, MH-60K, AH-1S, MV-22, CV-22, SH-60R, HH-60J, AH-1W/Z, UH1N/Y, EH101, and WAH-64D. At the end of production in July 2001, a total of 1192 systems will have been delivered. The last 160 units will be fielded in 2001.

The AVR-2A detects and categorizes laser threats as either rangefinders, target designators, or beamriders. Additionally, it identifies the direction of the threat, prioritizes threat according to lethality and displays threat data to the aircrew both visually and audibly. Currently, this information is displayed on the AN/APR-39A(V) or Multi-function display on the OH-58D. Ultimately, AVR-2A data will be fused through the use of SIRFC SEM-E cards and displayed to the aircrew on the Multi-function display or a dedicated Aircraft Survivability Equipment Display (ASED). The AVR-2A Laser Detecting Set can also be used for training by serving as a MILES/AGES receiver.

A horizontal technology insertion approach on improvements incorporated on the AN-VVR-1 Ground Laser Warning Set will be applied to the AVR-2A through an engineering change proposal in order to improve system performance and correct the ARC-220 Electromagnetic Interference (EMI) issues.

Sikorsky MH-60K Pave Hawk.

This upgraded system is currently identified as the Enhanced AVR-2A. The enhanced AVR-2A will increase system performance against improved and emerging threat systems, significantly improving angle of arrival information. Enhancements include 1553 Data Bus interfaces, EMI protection, reduced power consumption, reduced weight and a reduced system cost.

The potential tactical payoffs for integrating the SIRFC, ATIRCM/CMWS and the AVR-2A(V) systems are great. Integration will allow the systems to cue each other to the presence of RF tracking or acquisition radars, associated RF missiles, and unique IR-guided threats that use radar before launching a missile. Additional payoffs in addressing dual mode IR and RF guided threats will be made using sensor fusing capability and IR and RF jamming techniques.

AN/TPQ Aircraft Survivability Equipment Trainer (ASET) IV

The ASE training device strategy is a building block concept to train Army aviators on the proper employment of ASE. The ASE trainer (ASET) IV consists of a set of tactical threat emitter training devices which are used to teach realistic force-on-force and collective team training under the "train as you fight" concept.

Each ASET IV system set consists of two IR SAM threat simulators, one RF SAM threat simulator, two Anti-Aircraft Artillery (AAA) threat simulators, and a command and control vehicle. Six MAN-Portable Air Defense Systems (MANPADS) trainers are normally deployed with the ASET IV, but are not part of the system. The five threat simulators and command control vehicle are mounted on six M1097 High Mobility, Multipurpose Wheeled Vehicles (HMMWVs), which are designed to emulate a mechanized brigade based air-defense network. The ASET IV is used with all aircraft containing ASE systems. For the Army, these

include AH-1F, UH1H/V, RC12, CH47D, MH-47E, OH-58 C/D, EH-60A, MH-60K, UH-60A/L/Q and AH-64A/D platforms.

A major capability of the ASET IV system is the ability to conduct home station training, which assists a unit in developing tactics, techniques and procedures proficiency and increasing unit readiness. ASET IV provides tactical training against SAM and AAA threats. The ASET IV stimulates ASE and records the trainee counter-countermeasures response. The ASET IV threat emitters of the RF SAM and AAA have characteristics of enemy threat radars, which trigger the radar warning system and activate the jammer on board blue aircraft. The emission of a jamming signal by the aircraft can be detected and analyzed by the ASET IV for effectiveness and subsequent simulation of a realistic jamming response.

ASET IV production is complete and has received Congressional plus-ups for system upgrades. The fielding of one system to Fort Hood, another to Fort Campbell to support warfighter exercises and plans for fielding of the third system were accomplished during fiscal year 2000. Planned upgrades to ASET IV to provide night fighting capability via an IR camera, to upgrade the threats, and an upgrade to Operator Training, Interactive Multimedia Instruction were partially funded and began during FY98.

Dr. Steven Messervy is the Project Manager for Aviation Electronic systems for the U.S. Army Program Office at Redstone Arsenal, Alabama. He received his B.S. in Business Quantitative Methods from the University of Alabama and his M.S. in Management Research and Development from the Massachusetts Institute of Technology. Additionally, he holds a Ph.D. in Operations Research, Analysis and Statistics from the University of Alabama and his Sc.D. in Industrial Engineering from Southeastern Institute of Technology. Dr. Messervy is also the Army Principal Member and current chairman of the JTCG/AS Principal Members Steering Group. He may be reached at steven.messervy@peoavn.redstone.army.mil.

Mr. Steven Stegman is a member of the Army Acquisition Corps Competitive Development Group and the Defense Leadership and Management Program. He is the Deputy Product Manager for Radio Frequency Countermeasures. He received his B.S. in Industrial Engineering from Texas A&M University and his M.S. in Systems Engineering from the University of Alabama. He may be reached at steve.stegman@us.army.mil.

AIAA

American Institute of Aeronautics and Astronautics

Survivability Award Call for Nominations

Nominations due 1 Nov

The American Institute of Aeronautics and Astronautics (AIAA) is accepting nominations for the prestigious Survivability Award. Established in 1993, this award is presented to an individual or a team to recognize outstanding achievement or contribution in design, analysis, implementation and/or education of survivability in an aerospace system. The biennial award will be presented in April 2002 at the Structures, Structural Dynamics and Materials Conference in Denver, Colorado. Nominations must be submitted by 1 November 2001. Past recipients of the award have included Mr. Dale Atkinson, Dr. Robert Ball, Mr. Nikolaos Caravasos and Mr. Jerry Wallick. Forms can be obtained by accessing the following website: http://www.aiaa.org/Membership, or contacting Peter Gabriel of the AIAA Honors and Awards Office at 703.264.7623 or Dennis Williams of the AIAA Survivability Technical Committee at 314.232.7955.

Survivable Engine Controls

by Mr. Charles Frankenberger and Dr. Alan Pisano

The next generation of fighter aircraft will be powered by a new generation of turbine engines. These engines use the latest in digital control technology, and will provide significant advances in performance, operability, and health monitoring. Through these new technologies, advanced control algorithms provide an opportunity to reduce engine vulnerability and increase aircraft safety without reducing performance or adding weight. The JTCG/AS Vulnerability Reduction Subgroup has been sponsoring the Survivable Engine Control Algorithm Development (SECAD) project, which is taking advantage of these technologies, applying them in a new extreme manner.

Initial ideas for survivable engine controls (SEC) revolved around aircraft vulnerability reduction for single engine aircraft and to a lesser degree for twin engine aircraft. However, it quickly became apparent that detection of engine foreign object damage (FOD), and combustor burn-through events would also benefit peacetime flight safety. These events, like ballistic events, cause damage to the fan, compressor and combustor sections of the engine resulting in loss of engine performance.

SECs do not predict imminent engine failure and will not effect the result of catastrophic damage to the engine. Events that result in multiple blade loss and severe cascading damage will continue to cause the loss of the engine. SECs will however affect the results of events within an "intermediate" level of damage. In these cases, the engine component efficiencies will be significantly reduced well beyond normal operating points, and the engine will be operating in a significantly reduced power state. A large percentage of these types of damage go undetected by normal FADEC fault detection logic.

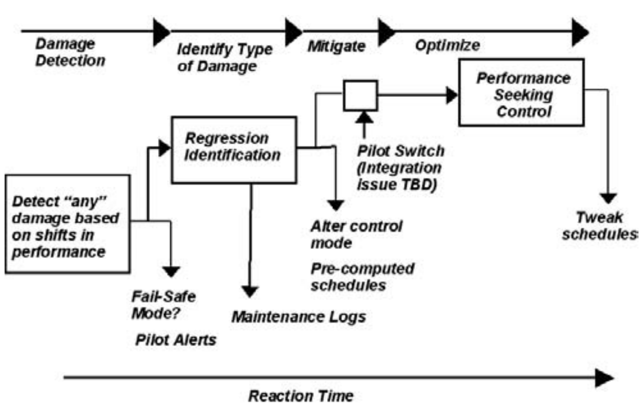

Figure 1. SECAD Detection—Mitigation Concept

What are survivable engine controls?

At their basic level, survivable engine controls monitor engine operation, detect damage to the engine that results in a shift in engine performance, and adjusts the engine control schedules to minimize the performance loss. The key to this technology is the ability to rapidly detect and classify engine damage. Engine damage propagates extremely quickly. As the engine performance changes due to the damage, the engine control reacts to the change, and in many cases perpetuates the damage resulting in fatal damage to the engine and possibly the aircraft. SECs monitor the engines critical parameters (speeds, pressures and temperatures) real-time to determine if damage has occurred. When damage occurs, the SECs algorithms simultaneously attempt to detect and classify the damage so that the proper mitigating control changes can be made. Figure 1, shows an overview of the SECAD architecture.

What engine failure modes were considered?

The types of failures which were considered in this study included: fan and compressor damage; combustor damage; and damage to the VEN.

Engine fan and compressor damage was selected to be representative of mechanical damage to the fan and/or compressor, consisting mainly of curling of the fan blade tips and some liberated pieces. This type of damage can be caused by ballistic events, such as impact with small warhead fragments, high-explosive incendiaries (HEIs), and small armor-piercing incendiaries (APIs). Fan and compressor damage can also be caused by FOD events, such as bird ingestion, ice ingestion, or runway and/or airframe FOD.

Combustor leak damage is representative of combustor case leakage caused by projectiles of various types, a lost combustor borescope plug, or any type of combustor case burn-through. Holes in the combustor case result in core airflow bleeding overboard. Leakage from the combustor can have a detrimental effect by altering high-pressure turbine (HPT) inlet temperatures on gas turbines that are temperature controlled by measuring low-pressure turbine (LPT) exit temperature and that do not measure and/or calculate HPT inlet temperature directly. The F414-GE-400 engine cycle model was modified to extract combustor airflow from holes up to 9 sq. inches at sea level/static (SLS) conditions. Results were matched with data (sizes and/or flows) obtained during engine testing and results corresponded very well. Other engine cycle models can be similarly modified.

VEN damage can result from several different scenarios. In one scenario, the VEN is forced open by aerodynamic loads when the fuel lines to the VEN actuators are severed or when the VEN feedback signal is lost due to damage. In another scenario, damage resulting from man-portable air defense (MANPAD) or ballistic impact destroys the VEN, either fully or partially (Figure 2). The current approach to modeling a fuel-line leak is to raise the VEN area schedule to its maximum limit (effectively forcing the nozzle open), which results in large thrust losses. This approach models an actuation system fuel leak, whereby the aerodynamic load forces the nozzle open. Performance data for this case was correlated with test data from China Lake data for a similar event (a fully failed case where the nozzle was forced to its physical limits).

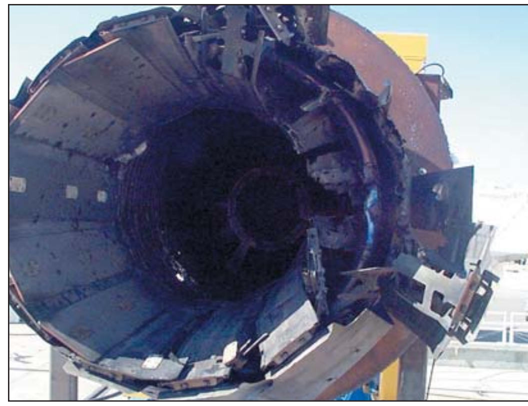

Figure 2. Damage resulting from man-portable air defense (MANPAD) or ballistic impact destroys the VEN.

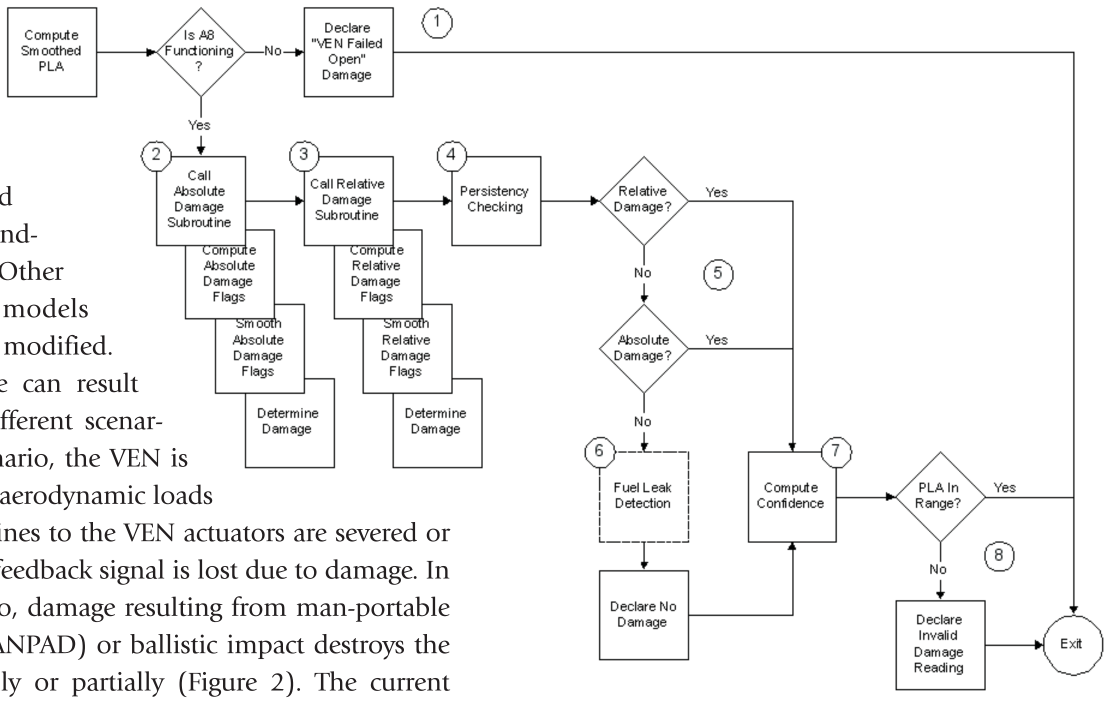

Figure 3. SECAD Detection Logic

How is damage detected and classified by SECAD?

SECAD uses an analytical method using both current values (absolute) and past values (relative) of the engine sensors. Essentially, a mathematical "model" of each damage scenario was built using data from hundreds of simulated engines with each damage type. Engine sensor values are the inputs to this model, and the damage level and type sustained by the engine are the outputs. For these initial studies, the model is then encoded using a linear regressor (i.e., the engine condition is approximated using a linear combination of sensed values). Figure 3 shows a simplified flowchart of the logic that combines both absolute and relative damage detection schemes and computes a final damage estimate based on multiple damage detection algorithms.

The FADEC has internal consistency checking to detect failed actuators, so VEN actuator

failure can be accommodated immediately based on the FADEC fault logic. If the FADEC does not detect a problem with the VEN, then the absolute-value damage subroutine and the relative-value damage subroutine are executed, and two independent damage estimates are produced. The damage estimates are checked for persistency so that transient behavior does not cause a false damage reading. The relative scheme reacts to damage more quickly and tends to be more accurate than the absolute scheme, so if it gives a damage result, it takes precedence over the absolute scheme. The relative scheme can be tricked into silence by transients and gradual damage, however, so if it detects no damage, the absolute scheme is polled for its results. If no damage is detected by either scheme, fuel leak detection is activated. Next, a confidence is computed for the damage estimate. The confidence is based on whether or not the two schemes agree, how long it has been since a throttle transient, etc. Finally, the power level is range-checked to make sure the engine is within acceptable operating conditions.

Once the damage has been detected and classified, how is mitigation done?

Once damage is detected, steps can be taken to minimize the negative effects and/or prevent engine failure. The objective of the mitigation action is to minimize these effects, while maintaining the greatest amount of engine capacity, whether it is maximum thrust or increased engine life. On FADEC controlled engines, it is possible to alter some or all of the control schedules: e.g., fan and compressor rotor speeds, variable guide vane position, variable exhaust nozzle position, afterburner scheduling, combustor fuel flow, low pressure turbine exit temperature, accel and decel schedules, and others.

For fan and compressor damage, attempts to restore some of the lost engine airflow can be achieved by raising fan and core speeds to max physical limits where possible. This will effectively raise the mass flow through the engine, restoring some thrust. Consideration needs to be given to elevated low pressure turbine exit temperatures and elevated fan operating lines. Variable guide vane scheduling can be adjusted to enhance off design point compression system efficiency. Also, accel and decel schedules will need to be adjusted to reflect changes in fan and compressor stall margins.

In the case of combustor damage where core airflow is bleeding overboard (whether from a ruptured combustor case or even a leaking customer bleed system), it is critical that it is quickly detected and corrective action taken before the turbine nozzle and blade damage occurs. Once the event is detected, over-temping the turbine can be prevented by establishing a new Low Pressure Turbine (LPT) exit temperature schedule consistent with the level of core airflow loss. (Lowering the LPT exit temperature will lower the operating line of the engine, effectively lowering the High Pressure Turbine operating temperature). For engines controlled by exhaust gas temperature, the relationship of LPT exhaust temperature rise per percent bleed loss (bleed level in lbs./sec, divided by core airflow in lbs./sec) will need to be established beforehand. The exhaust temperature schedule can then be lowered by this relationship for each percent of bleed loss detected.

For VEN damage, engine airflow is increased within operating limits to attempt to restore some of the lost thrust. This may require rescheduling the variable geometry system. If the loss of VEN control is due to severing of the hydraulic lines then it would be necessary to have fuel shutoff valves in these lines to prevent hydraulic fluid from collecting in the aircraft nacelle and creating a fire hazard. For VEN ballistic damage, mitigation strategies are similar to Loss of VEN Control and include raising fan and compressor speeds to increase engine airflow.

How was SECAD tested?

SECAD was tested on a F414-GE-400 engine at NAWCWD Weapons Survivability Laboratory during late September 2000. Each damage scenario was evaluated with the engine running at full military power (PLA=98). A part power condition was also tested (PLA=90) but no mitigation was done (intentionally).

For each case, the SECAD algorithm was turned on; the engine accelerated to full military power; the damage was "created;" finally mitigation was applied once SECAD detected the failure. With the exception of VEN

ballistic damage, all damage was introduced without actually damaging the hardware.

How did SECAD perform?

For fan and compressor damage, the "damage" was introduced using the bypass air from a TF30 engine placed in front of the F414 under test. This hot gas ingestion, made it appear that the fan efficiency was reduced thermodynamically. SECAD correctly detected and identified the damage. The net effect of the specific level of damage introduced was a loss in thrust of 7 percent of which SECAD was able to gain back 4 percent after mitigation (Figure 4).

Inserting various size orifices (1″, 1.5″, 2″, and 2.5″) in the customer bleed line simulated combustor damage. For all but the 1.0″ case, SECAD successfully detected the damage. This was to be expected, since the flow through the 1.0″ orifice is within normal operating range. As an example of mitigation, with the 1.5″ orifice, the thrust dropped 14 percent and SECAD was able to gain back 6 percent.

VEN loss of control damage was simulated both by control action as well as dumping actuator flow. SECAD again correctly identified damage in all cases but one. A minor change in the algorithm would have fixed that.

Unfortunately, when VEN ballistic damage was produced by actually firing a shot at the VEN, not enough damage was created for SECAD to react. However, subsequent analysis of the data pointed to a simple modification, which will allow us to detect "partial" as well as "complete" damage to the VEN. In summary, the SECAD test at China Lake was highly successful, and worked as designed.

Summary

As the concept of SECs evolved, it became apparent that pilot notification is an important feature. Many of the damage scenarios that SEC will detect, are not detected by the FADEC. Thus, without SEC, there is no pilot cuing that an engine has been damaged. For a multi-engine aircraft, the pilot must determine which engine has been damaged, the extent of the damage and what to do with the damaged engine based on a limited number of engine parameters. An immediate benefit of SEC is to provide damage cuing to the pilot, i.e., "LEFT ENGINE DAMAGE". This would free the pilot from this decision process to perform the many other tasks required.

Figure 4. Hot gas ingestion to simulate fan and compressor damage.

Proper damage mitigation allows the pilot to take the right corrective action based on his current situation. If damage occurs in a hostile area or immediately following a catapult launch, providing the most thrust available from the damaged engine could make the difference in survival of the event. During less stressing scenarios, after engine damage has been detected and mitigation invoked, the pilot could simply pull back power or shut down the damaged engine on a multi-engine aircraft.

Recent technology advances in controls systems provide the foundation for new concepts like SECs to be explored. Digital controls make it possible. Through these advances, and with technologies like SECs, engine safety and survivability will be significantly improved.

Mr. Frankenberger has worked in the propulsion field at NAWCWPNS for 12 years, including 8 years in missile propulsion on programs including Tomahawk, Harpoon/SLAM and Advance Air-to-Air Missile. he has worked in Engine Vulnerability issues for the past 4 years conducting ballistic tests on turbine engines under JTCG/AS and LFT efforts. He may be reached at 703.939.8411.

Dr. Alan Pisano has worked for General electric since 1968 where he was a member of the GE Advanced Course in Engineering program and received his MSEE and Ph.D. Since 1974 he has worked in the controls technology area, applying state-of-the-art controls to advanced turboshaft and turbofan engines at GE's Lynn, MA facility. He is the prime technology contact in the controls "Center of Excellence" and coordinates GAAE Lynn-based controls technology programs. He may be reached at alan.pisano@ae.ge.com.

Army S&T Program for Aircraft Survivability

by Mr. Malcolm W. Dinning and Mr. Bruce S. Tenney

Army aviation is adjusting to a significantly different operational environment than we faced just 10-15 years ago. No longer are low intensity conflicts characterized by low-tech ballistic weapons. Since the end of the cold war, there has been an explosion in the proliferation of state-of-the-art threat weapon systems. These first-line weapons are equipped with upgraded sensors and ruggedized signal processors that significantly increase their ability to detect low altitude tactical targets in clutter. Nearly all of these threats also employ sophisticated counter-countermeasures (CCM) capabilities, such as jam resistant logic and decoy discrimination capabilities that has eroded the effectiveness of our current aircraft survivability equipment.

At the same time, operational constraints make these missions tougher. Weapons and targeting systems that are very effective against massed armor forces are not nearly as effective in low intensity conflicts where combatants and non-combatants are co-mingled. Kosovo operations highlighted deficiencies of our stand-off capability against targets other than large, easily identified structures, such as buildings and bridges. Against smaller targets it was more difficult to differentiate military wheeled vehicles from civilian wheeled vehicles at survivable stand-off ranges. The necessary need to avoid civilian casualties and collateral damage requires that we close sufficiently to positively identify the target rather than engage on classification alone. This reduces our stand-off advantage and puts us more directly in harm's way. These limited scope military operations in urban terrain (MOUT) represents environments that today, we are poorly positioned to dominate in, but the reality is that they are where we have the highest probability of fighting in for the foreseeable future. General Shinseki is addressing these shortcomings as part of the Army's transformation into a lighter, more agile, yet highly lethal and survivable Objective Force. The Army's Science and Technology community has been developing new survivability technologies for this Objective Force to allow us to effectively operate and dominate in these new battlefield environments.

Army aviation's approach to next-generation survivability focuses on three main S&T thrusts—susceptibility reduction technologies to minimize threat engagement performance, enhanced situational awareness technologies that permit effective tactics, and vulnerability reduction technologies to protect the aircraft and aircrew from loss.

Susceptibility Reduction

Susceptibility reduction includes both passive signature reduction and active countermeasures. Signature reduction not only delays and degrades threat acquisition, but also enhances jammer performance by increasing jamming/signal (J/S). Fielding a lightweight, affordable, and yet highly effective countermeasures suite requires that it be developed as an integrated, complementary system, rather than as a set of competing components. The goal of our S&T signature reduction efforts is to reduce the aircraft contrast to a level that provides both an operationally meaningful reduction in threat acquisition ranges and enhances the performance of our active countermeasures to bring us home. The high agility and moderate speed of rotorcraft allows for maximum use of terrain to increase both the clutter energy and false alarm rates received by threat sensors, both radio frequency (RF) and infrared (IR). This significantly reduces the level of signature reduction required for low contrast and low detectibility, and is the key to affordable, fieldable, and survivable forward-deployed (in the mud) tactical aircraft.

The Comanche aircraft design represents the culmination of years of S&T signature management work. Engines are internal with flush inlets. Weapons are carried internally and deployed just seconds before launch. Even the 30mm gattling gun is stored in a low radar signature fairing when not in use. The aircraft incorporates

a complete air management system to control thermal signatures. Cockpit environmental control unit (ECU) refrigerated air is reused and ducted to the electro-optic sensor system (EOSS) assembly as cooling air, which is then further reused and ducted to the gun fairing to cool the barrel after firing and stowage. ECU and auxiliary power/propulsion unit (APU) exhausts are routed to the main engine exhaust that is cooled with an internal advanced IR suppressor. Current S&T efforts are focused on developing advanced engine IR suppressor systems for current fleet upgrade. High efficiency nozzle/ejectors are being designed to increase cooling flow, without adversely impacting engine performance.

IR threats are becoming significantly more sophisticated in their ability to resist deceptive jamming and decoys. Directional laser jammers, such as the Advanced Tactical IR Countermeasures (ATIRCM) system, were developed to overwhelm the CCM circuits of current and emerging jam-resistant IR missile seekers. At the same time, a new Suite of Integrated RF Countermeasures (SIRFC), is finishing development and testing. SIRFC employs improved deceptive jam waveforms that attack Moving Target Indicator (MTI) and pulse doppler tactical radar signal processors.

Coupled signature reduction and active countermeasures are very effective at reducing the lethal boundaries of threats and opening gaps in the air defense network. However, in-cockpit situational awareness is needed to fully exploit the benefits that active/passive technology brings, by identifying these gaps to the aircrew. Situational awareness drives effective tactics, techniques and procedures (TTPs), and ultimately mission success. Battlefield information dominance represents a true leap-ahead capability that provides our best opportunity at revolutionizing the way we fight and win on tomorrow's battlefields. Army aviation, through the Rotorcraft Pilot's Associate (RPA) program, has successfully demonstrated the effectiveness of advanced Cognitive Decision Aiding algorithms to process multiple on-board and off-board high-bandwidth data streams into display symbology and cuing information that provides situational understanding at a glimpse. Functionality demonstrated through the RPA program includes—Attack, Route, Sensor, Recon, Com/Nav, and Survivability Planners. The Army's Communications and Electronics Command (CECOM), located at Ft. Monmouth, NJ. is developing advanced sensor suites, such as the Integrated Situational Awareness and Targeting system, that will significantly improve the accuracy of threat localization, critical to assessing threat lethality to ownship.

Vulnerability Reduction

While these technologies greatly reduce our susceptibility to threats, we must still protect against those projectiles and warhead fragments that do make it to the aircraft. Army aviation has invested heavily in technologies that allow our aircraft to absorb tremendous punishment and keep flying. Flight controls are redundant and all critical flight components are hardened to withstand 7.62mm impacts and many up to 12.7mm. Higher caliber high explosive, incendiary (HEI) rounds send a fragmentation pattern that weakens airframe structures, followed by blast overpressures causing it to fail. We've developed sacrificial skins and blow-out panel technologies that provide a flow path for the blast gases without overstressing the airframe. Transmissions designed for 30 minutes of operation without oil have been developed and are currently being fielded. Next generation ceramic and transparent armor is being developed for lightweight protection against high energy projectiles (12.7mm and up). Unlike fixed wing pilots, when an Army aviator straps a helicopter to his back, he or she is going to stay with it no matter what. While the aircraft is designed to take a lot of abuse before it gives up, when it does, crashworthy systems are critical to insuring that the aircrew survives and hopefully, walks away. The development of new, structurally efficient composite airframe technologies evolves around energy absorption under crash loads. Energy absorbing landing gear, stroking seats and crew restraints are designed to transmit survivable deceleration forces to the aircrew. Cockpit airbags, just completing development and currently transitioning to fleet aircraft, are designed to reduce head and arm flailing injuries, typical of crash and post-crash roll-overs. Crashworthy, self-sealing fuel tanks, quick disconnect fuel lines, fuel tank nitrogen inerting systems and powder packs

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Low Altitude Helicopter Combat Operations

Ballistic & Chemical/Biological Survivability

by Mr. Gerald J. Burblis

Today's air vehicle systems conduct combat operations in an extremely hostile environment. The challenge of defeating or evading current operational air defense systems is a monumental task for all air vehicle systems, but even more so for the helicopter. Rotary wing systems have to operate in very close proximity to the ground to avoid detection, increasing their vulnerability to anti-aircraft guns, surface to air missiles, MANPADS, and directed energy systems. This makes their survivability requirements unique based on their proximity to the threat systems. The helicopter must take advantage of every potential defensive feature whether onboard or on the ground. Incorporating defensive features into today's helicopters is even more difficult than in the past. The helicopters of today require speed, range, endurance, enhanced threat detection, line-of-sight targeting and extensive communication capabilities. Relaying real-time knowledge of the battlefield environment is essential to surviving and winning the conflict. To effectively package all the required defensive features into an optimized design which offers ballistic tolerance, chemical/biological resistance, directed energy protection, low radar detectibility and minimal infrared signature is no easy task.

The most prolific, readily available and damaging threats fielded today are of a ballistic nature. To minimize helicopter vulnerability to this type of threat requires extensive trade-off studies to down select those features offering the most protection for their weight, complexity, maintainability, volume, and cost. Vulnerability reduction features must be focused on the individual system's primary and secondary mission profiles, and take into consideration the most likely threats to be encountered when performing those missions. The process of formulating and utilizing ballistic survivability assessment methodologies, along with associated research and development programs, is the key to effectively arriving at a system level design which optimizes ballistic tolerance. The use of state-of-the-art codes to develop a detailed target model description for shotline interrogation is essential. Once the target model is complete, a shotline assessment is performed to determine those systems, subsystems, and/or components, which are the largest contributors to the air vehicles total vulnerable area value. Once identified, each system/component is reviewed in a trade-off study process to determine what changes, if any, can be incorporated to reduce ballistic vulnerability to the system specification threat(s). In addition, new systems under development must also consider Live Fire Test & Evaluation (LFT&E) requirements and associated battlefield threats against which their particular system will be evaluated. In some instances the LFT&E process will mandate that the design be evaluated for ballistic threats which are above the system level specification requirements since they could be potentially encountered, based on mission profile, on the battlefields of today and the future. Successful demonstration of effective ballistic survivability solutions is the key to developing an optimized system for survival in the low altitude combat environment.

Modern air vehicle systems must also take into account the potential for encountering other unique and emerging battlefield threats while conducting low altitude combat operations. The chemical/biological threat is becoming more prolific and readily available on today's battlefield. Many countries have stockpiled the chemical/biological threat and have the operational systems capable of delivery. Even if the chemical/biological threat were not used effectively, as with untrained adversaries who lack knowledge of it's most effective use, the resulting consequences of even limited use could potentially be disastrous. Systems not designed to effectively resist the threat would be at risk. Their operational combat effectiveness would suffer, time and effort associated with weapons rearming and refueling would increase dramatically, maneuvering options could be hindered and decontamination would be one more variable to add to the battlefield equation.

Operating in very close proximity to the ground subjects the helicopter to the same battlefield threat environ-

ment as the ground units. To minimize helicopter vulnerability to this type of threat requires numerous trade-off studies during the early phases of the design process to down select those features offering the most protective merit based on their weight, volume, ease of maintenance and cost. Vulnerability reduction features must be focused on the individual system's primary and secondary mission profiles, and take into consideration the most likely threat type to be encountered.

The process of formulating and utilizing chemical/biological survivability assessment methodologies is the key to effectively arriving at a system level design. This optimizes chemical/biological tolerance. The first step is to conduct a chemical/biological contamination survivability assessment, since it is essential to identify the materials used in the construction of an aircraft. This comprehensive approach is necessary since many components, though not flight critical or mission essential, could pose a significant hazard to flight and ground crews if they were susceptible to the absorption of contaminants and presented the possibility of outgassing at a later time with deadly effects. Following this review, only those parts identified as susceptible to contaminants would be included in the assessment. Next, the air vehicle is regionalized to establish exactly where the susceptible components are located and to support considerations for collective protection features. An investigation is then conducted to establish airflows in and around the aircraft. The purpose of this effort is to determine the potential for component exposures based upon contaminant infiltration and deposition points.

The results of the chemical/biological assessment provide a "wish list" for potential chemical/biological protective features which can be incorporated into an air vehicle at the very earliest phase of the system's design or in a phased process over time. Successful demonstration of effective chemical/biological survivability solutions is the key to developing an optimized system for survival in the low altitude combat environment.

Mr. Gerald J. Burblis has 34 years of aeronautical experience at Sikorsky Aircraft. He has extensive knowledge in weapon's integration and foreign weapon threat characteristics. For the past 10 years he has been the lead for all Boeing/Sikorsky NBC and Ballistic vulnerability reduction activities on the RAH-66 Comanche Program. He may be reached at 203.386.6092.

Army S&T Program for Aircraft Survivability

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have been developed and fielded to reduce post-crash fire occurrence.

Aircraft survivability has long been associated with the individual elements of the survivability chain: don't be detected, don't be engaged, don't be hit, and don't be killed. Army aviation addresses each of these elements as an integrated survivability system of systems, with each component a critical part of the whole. The overlapping protection provided by this approach maximizes aircraft survivability against the full-spectrum of threat weapons populating low and high intensity battlefields. Science and Technology initiatives have been the foundation of our current fleet capabilities and are critical to next-generation future aircraft systems.

Mac Dinning is the Signatures Technology Team Leader at the US Army Aviation Applied Technology Directorate (AATD) at Fort Eustis, Virginia. He is directly responsible for assessing current and future Army fleet susceptibility needs and developing appropriate signature control hardware. Mr. Dinning has also functioned as the Aviation and Missile RDEC survivability lead for Comanche for the last 10 years. He holds a Bachelors degree in Aeronautical Engineering from the California Polytechnic University. He may be reached at mdinning@aatd.eustis.army.mil.

Mr. Tenney has a B.S. and M.S. in Electrical Engineering from West Virginia University. Mr. Tenney has been responsible for multiple advanced development projects in target acquisition, weapons, and mission equipment integration. He was the Program Manager for the Rotorcraft Pilot's Associate (RPA) program. Mr. Tenney is the Chief of the Systems Integration Division where he is responsible for science and technology development and engineering support in Weapons and Target Acquisition; Signature Management; Avionics; and Manned/Unmanned Systems. He may be reached at btenney@aatd.eustis.army.mil.

calendar of events

AUG

14–16 — Orlando, FL
National Test and Training Conference
Sponsored by NDIA and DOT&E
Contact: Sam Campagna, 703.247.2544
www.ndia.org

21–23 — China Lake, CA
JLF MANPADS IPT
Contact: Al Wearner, wearneraj@navair.af.mil, or
john.murphey@wpafb.af.mil

28–30 — Albuquerque, NM
Space 2001 Conference/Exposition
Contact: www.aiaa.org

29–30 — U.S. Air Force Laboratory, Kirtland AFB, NM
3rd Air & Space Protection Conference
Protection & Integration of Air & Space
Contact: 1-888-OLD-CROW
http://www.crows.org

NOV

5–9 — Dayton, OH
11th Annual Aircraft Fire Protection/Mishap Investigation Conference
Contact: AFP Associates,
www.aol.com/afp1/www.htm

5–9 — Monterey, CA
Aircraft Survivability Symposium 2001
Sponsored by NDIA
Contact: Joe Hylan, 703.247.2583

6–8 — Charlottesville, VA
BLUEMAX, ALARM, RADGUNS User Group Meeting
Contact: SURVIAC, Paul Jeng, 937.431.2712

27–29 — Nellis AFB, NV
Brawler/ESAMS User Group Meeting
Contact: SURVIAC, Paul Jeng, 937.431.2712

Information for inclusion in the Calendar of Events may be sent to:

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